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EXPERIMENTAL PERFORMANCE OF A 15 KILOWATT CW CO2 ELECTRIC DISCH--ETC(U)
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EXPERIMENTAL PERFORMANCE OF A 15 KILOWATT CW CO_2 ELECTRIC DISCHARGE LASER

AIR FORCE AERO PROPULSION LABORATORY
AFAPL/POD-1
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOVEMBER 1977

TECHNICAL REPORT AFAPL-TR-77-74
Final Report for Period January 1976 – July 1977

AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This report contains the results of an effort to fabricate a CO_2 laser. The work was performed in the Aerospace Power Division of the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio, under Project 3145, Task 32 and Work Unit 31. The effort was conducted by Douglas C. Rabe/AFAPL/POD-1 during the period January 1976 to July 1977.

This report has been reviewed by the Information Office, (ASD/OIP) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Douglas C Rabe

DOUGLAS C. RABE
Project Engineer

FOR THE COMMANDER

Richard L Verga

RICHARD L. VERGA
Technical Area Manager
High Power Branch

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The fabrication and initial experimental checkout of an Electric Discharge Laser (EDL) System is described. This continuous wave carbon dioxide laser extracts power in excess of 12 kilowatts routinely at an electrical discharge efficiency of 27% and a mass flow efficiency in excess of 100 Kw/lbm/sec. With the current resonator optics, the output intensity distribution is circular, uniform and repeatable to within 5%. This laser has performed over 8,000 experiments ranging from 1 to 10 seconds in duration.

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FOREWORD

This report contains the results of an effort to fabricate a 10 kilowatt CO_2 laser. The work was performed in the Aerospace Power Division of the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio, under Project 3145, Task 32 and Work Unit 31. The effort was conducted by Douglas C. Rabe/POD-1 during the period January 1976 - July 1977.

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SECTION I

INTRODUCTION

This report describes the fabrication and experimental evaluation of a 12 kilowatt coaxial electric discharge laser built by the Air Force Aero Propulsion Laboratory for the Air Force Materials Laboratory with cooperation and consultation from the Air Force Weapons Laboratory. Patterned after the Electric Discharge Coaxial Laser (EDCL) at the Air Force Weapons Laboratory, this laser will also produce a circular radially symmetric intensity distribution with spatial uniformity of $\pm$ 5 percent. Since the AFWL EDCL is described fully in Reference 1, the intent of this report will be to add additional information in the design and fabrication data and present an alternative operating mode of the laser.

SECTION II

FABRICATION

This section will discuss the facility aspects of the laser system constructed at Wright-Patterson Air Force Base, Ohio, which were changed from the original design or are considered important when constructing a similar laser facility. It is understood that any organization building such a machine would make many changes to suit their particular requirement; however, this section of the report will aid in a new design by giving another concept with which the original EDCL at AFWL can be compared.

This laser was designed and fabricated in the ten month period from January to October 1975 at a total cost to the government of $100,000.00. However, it must be kept in mind that this amount did not include the substantial cost of the evacuation system.

Since this laser system was installed in the facility to be used solely for laser countermeasures experimentation, certain aspects of its fabrication are different from the original EDCL and these aspects will be discussed by briefly outlining the three major systems that make up the total laser system.

1. Gas Supply and Vacuum System:

The gas supply for the laser consists of two tube trailers, approximately 33,000 SCFM each, for helium and nitrogen and six standard size gas storage bottles of carbon dioxide. With the average frequency of 30 runs per day, the helium trailer must be filled every six to seven weeks. Depending on the availability of helium and the desired frequency of operation, this could result in significant downtime due to inadequate gas storage alone.

Regulated to approximately 500 psig out of the gas storage, the He and N_2 are passed through 100 feet of 3/4 inch copper tubing connected together with standard Swagelock fittings. The CO_2 is also regulated down to approximately 600 psig and then passed through 50 feet of 1/2 inch copper tubing which is heated by a strip heater to prevent solid CO_2 from entering the laser. Within 10 feet of the laser entrance, each of the three gases passes through a valve, a dome regulator and an orifice which fixes the mass flow rate depending on the regulated pressure and the orifice size. The three lines are then joined by use of a cross fitting and the single supply line is controlled by a 2 inch ball valve. A picture of the gas regulating system is shown in Figure 1.

The gas is taken into the test facility and "teed" into two 4 inch diameter stainless steel lines which deliver the gas equally to each end of the laser cavity where it is fed radially to the two ends by eight 1.5 inch diameter lines (see Figures 2 and 3).

The gas exits out of the laser cavity through one 10 inch stainless steel line 100 feet long to the vacuum chamber and pumps. The vacuum system used in this facility was an existing high vacuum space chamber (see Figure 4). With a volume of 23,000 cubic feet and a pumping capacity of 4,300 ft^3/min, the space chamber enables the laser system to operate ten second runs approximately every five minutes. It is recommended that the largest vacuum system available or affordable be obtained, since this system will generally determine the cycle time of the laser facility.

2. <u>Power Supply and Current Regulator System:</u>

A 300 amp 440 volt service was required for operation of the Universal Voltronics power supply purchased for this laser. This power supply is capable of supplying 25 kilovolts at 4.55 amps. From the power supply, the output is taken to

six current regulators; three current regulators then feed 16 ballast resistors and the corresponding 16 anodes of each end of the laser cavity (see Figure 5). The current regulator is described in detail in Reference 1 and the detailed electrical schematic and layout of the regulator fabricated for this laser is shown in Reference 2. Figure 6 shows the original completely enclosed current regulator. A subsequent modification has been made to this regulator by insulating the complete front face and a major portion of the floor. This modification was required to prevent arcing of the components at the higher power runs.

It is recommended that the power supply be obtained with the ground detached from the negative of the high voltage output. This will enable the two to be connected at the cathode of the laser without resulting in a ground loop in the high power circuitry.

3. <u>Laser Cavity and Optical Resonator:</u>

The laser cavity is shown in Figure 3 and is described in detail in Reference 1. Of major importance to the facility operation of a high power laser is the mounting of the optical cavity. Figure 3 can be compared with Figure 15 of Reference 1 for the differences in the laser support. When first operated, this laser was aligned and then not adjusted for over 3 months of operation. It is now routinely checked and aligned every other week.

The high voltage shielding of the present laser is quite important when operating such a device in a routine facility manner. The complete laser is shielded from the occupants of the test facility by a one inch Plexiglas cover and the target is placed in an adjoining test room that is also blocked off from the operators and investigators during the test run. The operational setup of the overall test facility is more fully described in Reference 3.

The resonator optics presently consist of a totally reflecting back mirror with a radius of curvature of 15 meters and a flat zinc selenide output window with an overall 70/30 reflection transmission capability. Because two windows have failed since the initial turn on of the laser system, an extensive investigation was made of the optical configuration and stress relating to the power transmission. This analytical investigation of the output window is described in Reference 5. The investigation concluded that the first two windows absorbed 14% of the incident energy and this absorption resulted in the window failing at long run times. The present window absorbs .80% of the incident energy and should be able to transmit 10 Kilowatts for 10 seconds repeatedly.

SECTION III
EXPERIMENTAL LASER PERFORMANCE

1. Electric Discharge:

The performance of the electrical components of the laser system was investigated for two power settings and one gas flow condition: the gas flow condition was cold flow pressure of 25mm Hg with a gas ratio of He: N_2: CO_2 of 32:48:20. The electrical conditions are referenced to the no load voltage set on the power supply and were: 16.7 and 14.7 kilovolts. The high voltage probe was placed at the locations indicated in Figure 5 and are classified as follows:

Location	
1	Power Supply Ripple
2	Current Regulator Ripple
3	Discharge Ripple

For base conditions the power supply was investigated by shorting out the channel and measuring the voltage ripple at location one. This is shown in Figure 7.

Since the laser is sometimes operated with only one side discharging, the voltage ripple on the various components was measured for the two conditions, one side discharging and both sides discharging. The comparison was conducted at 16.7 kilovolts set and is shown in Figures 8-13. From these pictures it is shown that when one side is operating alone the voltage ripple out of the power supply is somewhat increased, in this case from 6% to 7%. However, it is also shown that for both sides discharging, about 1 kilovolt is dropped across the current regulator which results in a 7% power loss. Further, it is shown that the discharge voltage ripple is 6% for one side discharging, and 6.5% for both sides discharging, which indicates essentially no change across the discharge between the two cases. This also indicates that for both sides discharging the current regulators and ballast resistors are not reducing the power supply ripple while for the one side discharging case, is reduced 14% to 6% discharge ripple.

For the case of both sides discharging, the power supply voltage ripple of 6% is not reduced at the discharge by the uses of current regulators and ballast resistors. In the case of one side discharging, the power supply ripple of 7.0% is reduced to approximately 6% at the discharge by the related circuitry. This comparison indicates that the current regulators and ballast resistors are dissipating more fluctuations for the one side discharging case than for the normal two sides discharging.

To investigate the need for the current regulators, a second voltage setting was used. At 14.7 kilovolts set, the current regulators were removed from the circuitry and the results are shown in Figures 14 and 15. A power supply voltage ripple of 5.4% is observed for the case where the current regulators are in use, where a discharge ripple of 5.5% is observed across the discharge without the use of the current regulators. This indicates that without the use of the current regulators the discharge ripple is the same as the power supply voltage ripple with the use of the current regulators. Therefore, from the previous data the discharge ripple would be the same for the two cases of with and without current regulators for both sides discharging. However, for one side discharging the discharge voltage ripple would not be reduced the 14% as it is when the current regulators are in use.

The current ripple was also investigated with and without the current regulators at 14.7 kilovolts set and 16.7 kilovolts set with the current regulators and the results are shown in Figure 15. With and without the current regulators, the current ripple is about the same: 22%. This current ripple can be compared with the 9% ripple with both sides discharging. This is further indication that the imbalances of one side discharging require more effort from the current regulator system.

From this data, it is apparent that the current regulators are not needed for this laser system. The effects of aerodynamics as indicated by Reference 1 are sufficient to stabilize the discharge without the current regulators. As demonstrated, this laser system can be operated in a manner similar to that of the system described in Reference 4. Turbulent mixing, not shocking as incorrectly indicated in the reference, is sufficient to stabilize the discharge.

2. <u>Power Output and Beam Quality</u>:

Power output of this laser system has been measured up to 11.7 kilowatts in comparison with the national standard as reported in Reference 6. The power output obtained at the 16.7 kilovolts set conditions was 7.4 kilowatts with both sides discharging and 3.29 kilowatts for one side discharging. Calculating the power input to the discharge results in 27% power conversion within the laser discharge.

However, from a system design standpoint, the power conversion of the system is more important, and for this power setting is 18%. At the 14.7 kilovolts set condition, the power output for one side with the current regulator in the system was 2.59 kilowatts with a system power conversion of 13%. In contrast, the power output for one side without the current regulator was 3.86 kilowatts resulting in a system power conversion of 19%.

The beam quality obtained from the system is shown in Figure 17 and is considered to be ± 5% spatially uniform. Further quantitative investigations are being made of the beam quality and will be reported in subsequent reports.

SECTION IV

CONCLUSIONS

This laser system is by far the most effective method of obtaining high power output of uniform intensity distribution over the irradiated target. The system can produce power outputs routinely in excess of 12 kilowatts for periods up to 10 seconds. It has simplicity of construction, high reliability, low cost, and low volume in the test area. All of these features lend this machine significance as a laser effects and countermeasures system. It is further concluded that about 15% of the cost of the laser system constructed here could have been eliminated by deleting the current regulators and depending on the aerodynamic mixing.

REFERENCES

1. Carlson, Randolph L., A 15 Kilowatt CW CO_2 Coaxial Electric Discharge Laser, AFWL-TR-76-115, Air Force Weapons Laboratory, Kirtland AFB NM, August 1976.
2. Electrical System Data for Square Beam Laser, Contract No. F33615-73-D-0473, November 1975. Available from the author upon request.
3. The Laser Hardened Materials Evaluation Laboratory, Information for Users, AFML/LPJ TM-76-11.
4. Hill, Alan E., Hamil, Roy A., "Electro-Aerodynamic Laser Technology," Laser Division Digest LRD-71-2, Air Force Weapons Laboratory, Kirtland AFB NM, Fall 1971.
5. Roundeau, Roger E., and Ford, Dalye, Computed Temperature Response of the AFML Flat Top Laser Window, AFML-TM-LP-76-12, Air Force Materials Laboratory, Wright-Patterson AFB OH, September 1976.
6. Wellington, Roy O., and McLaughlin, Irvin L., Report to Sponsor, Results of the AFML/AGMC Intercomparison of Laser Energy Meters Driving, October 1976.

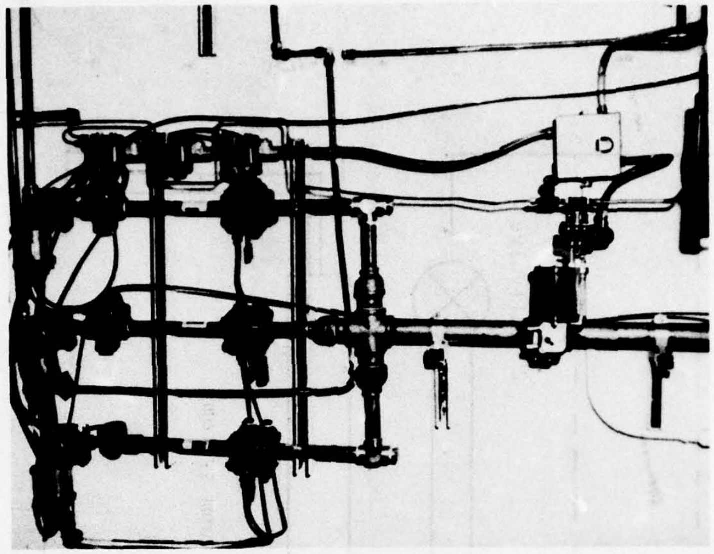


FIGURE 1 LASER GAS REGULATING SYSTEM

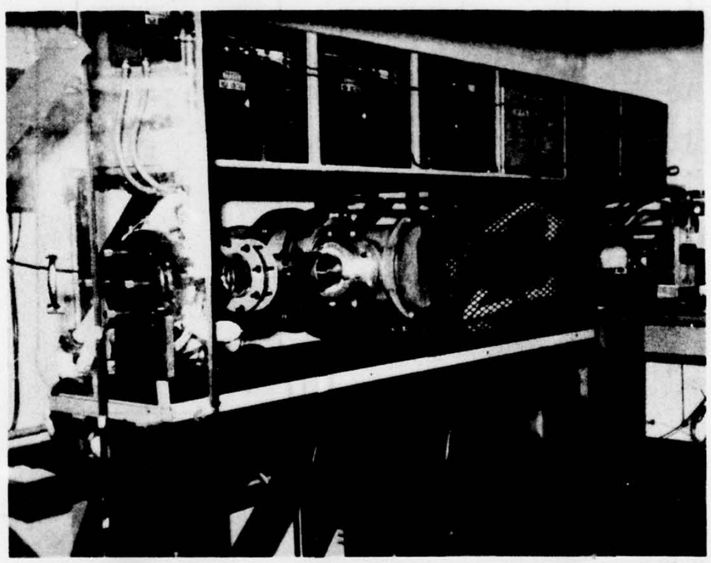


FIGURE 2 LASER CAVITY AND SUPPORT

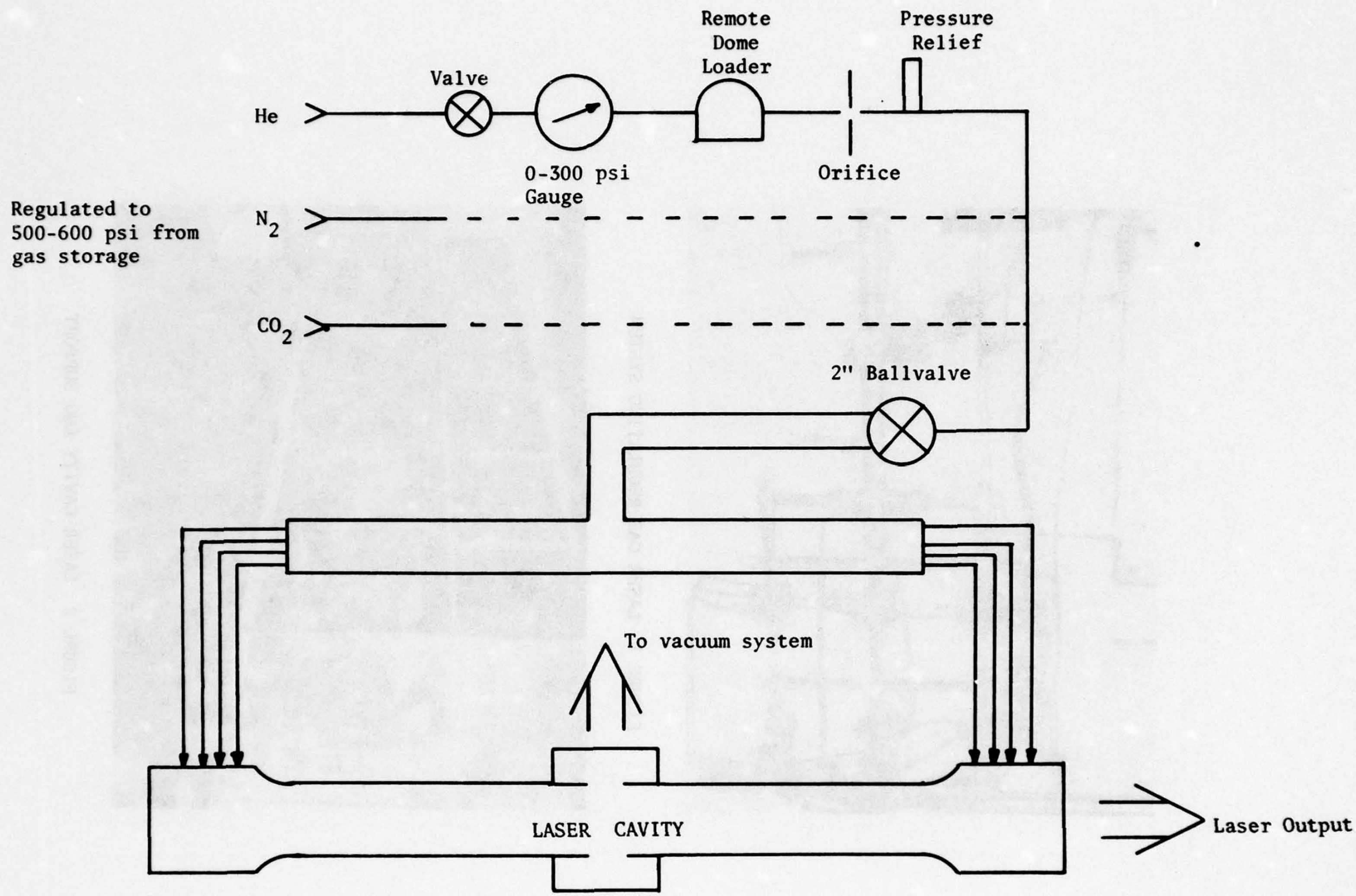


FIGURE 3 SCHEMATIC OF LASER GAS FLOW

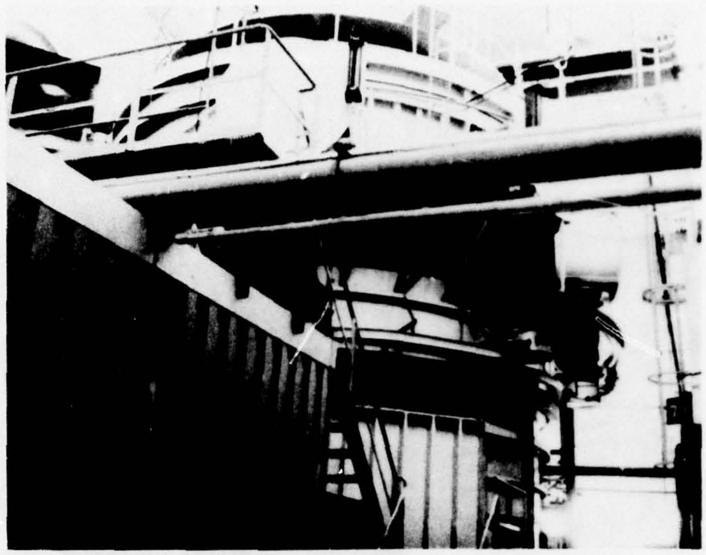


FIGURE 4 EVACUATION CHAMBER AND EXHAUST LINE

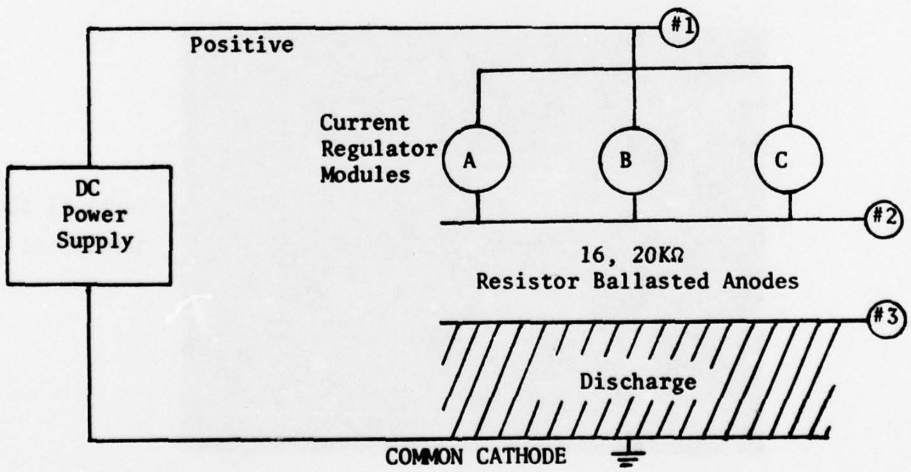


FIGURE 5 SCHEMATIC OF POWER SUPPLY DISTRIBUTION SYSTEM, FOR ONE SIDE OF LASER

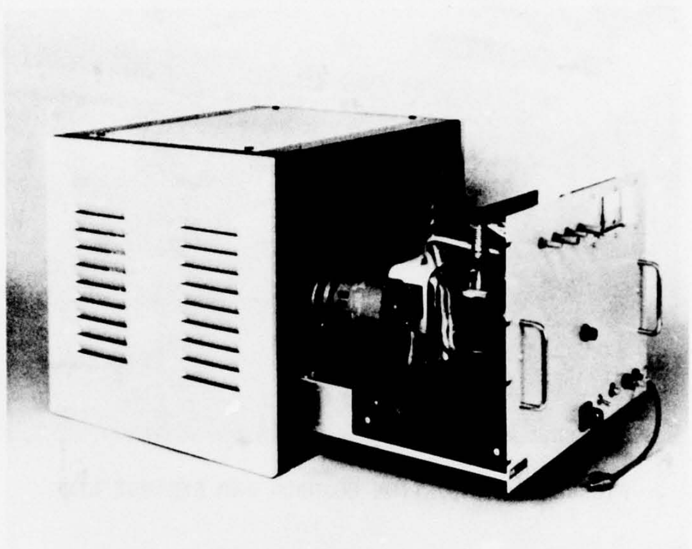
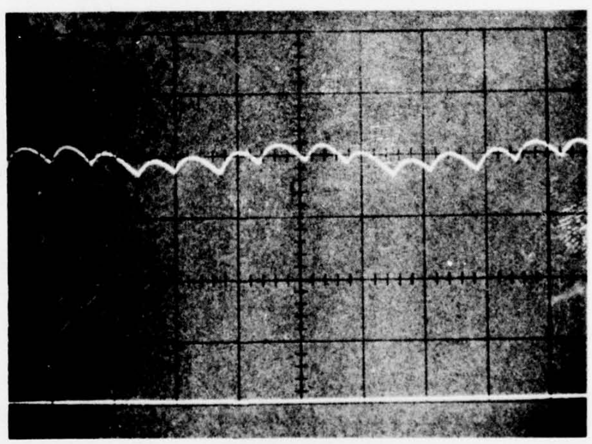
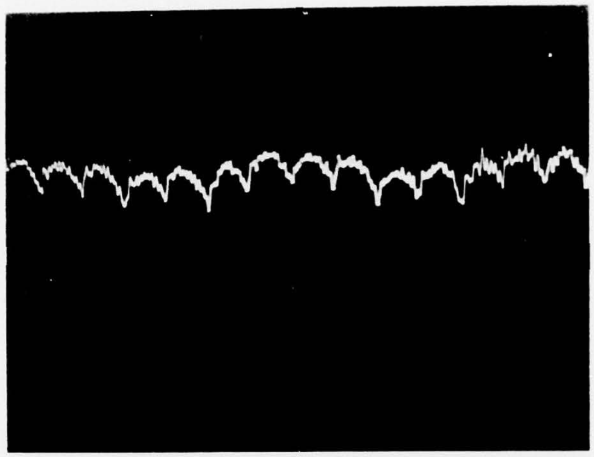


FIGURE 6 CURRENT REGULATOR MODULE



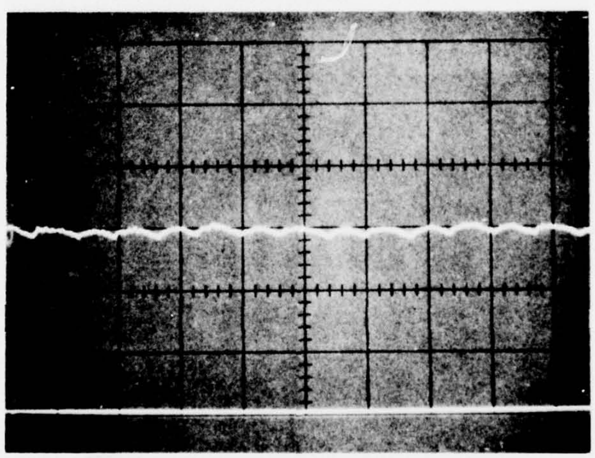
Vertical 500 volts/div
Horizontal 2msec/div

FIGURE 7 POWER SUPPLY RIPPLE WITH CHANNEL SHORTED



Vertical 1KV/div
Horizontal 2msec/div
16.7KV set
2.675 Amps

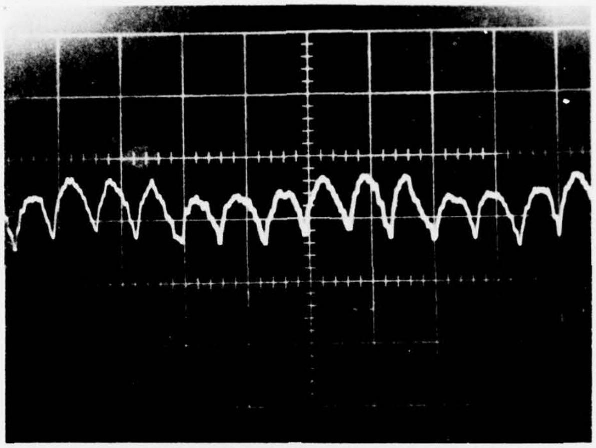
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
16.7KV set
2.65 Amps

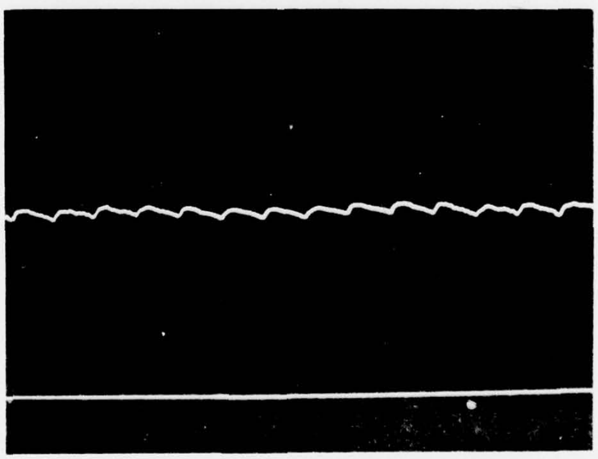
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 8 POWER SUPPLY RIPPLE WITH BOTH SIDES OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
16.7KV set
1.325 Amps

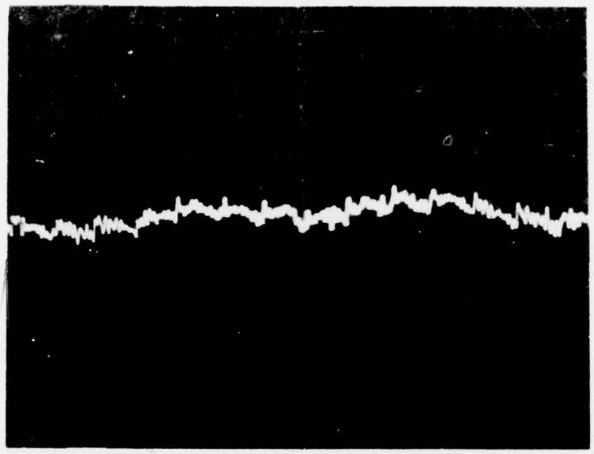
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
16.7KV set
1.325 Amps

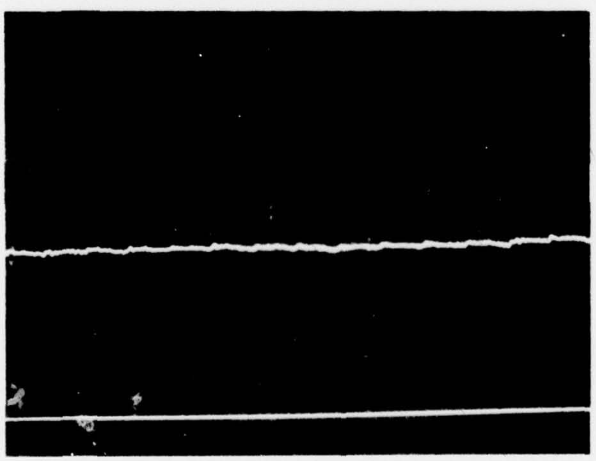
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 9 POWER SUPPLY RIPPLE WITH ONE SIDE OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
16.7KV set
2.675 Amps

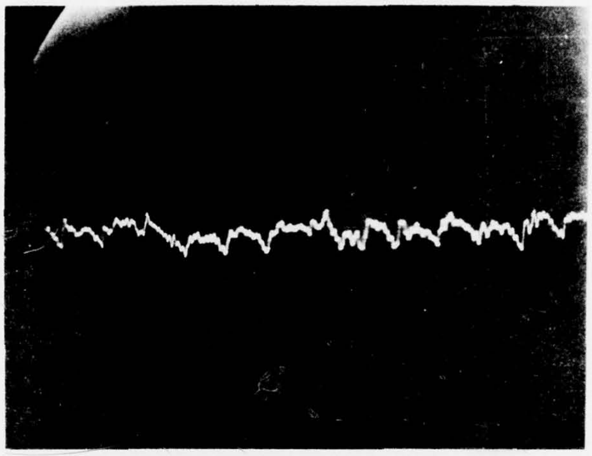
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
16.7KV set
2.675 Amps

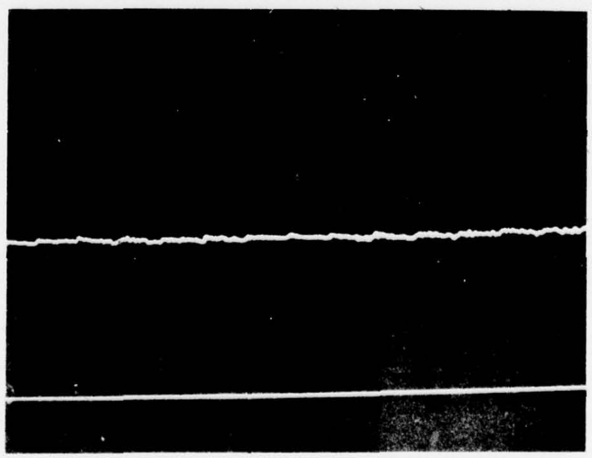
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 10 CURRENT REGULATOR RIPPLE WITH BOTH SIDES OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
16.7KV set
1.325 Amps

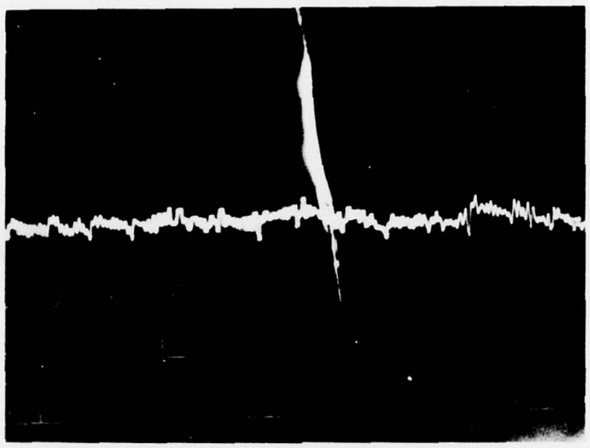
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
16.7KV set
1.325 Amps

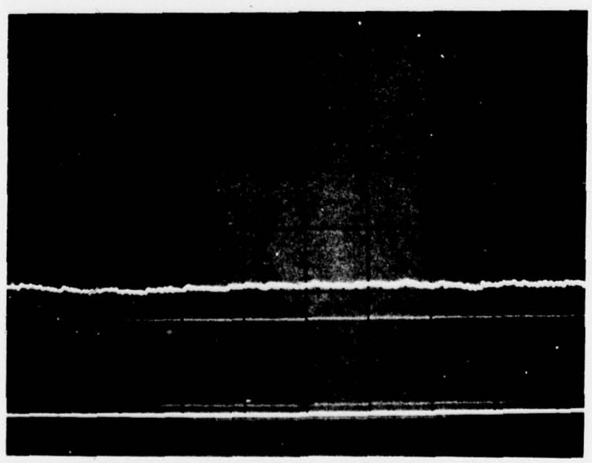
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 11 CURRENT REGULATOR RIPPLE WITH ONE SIDE OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
16.7KV set
2.7 Amps

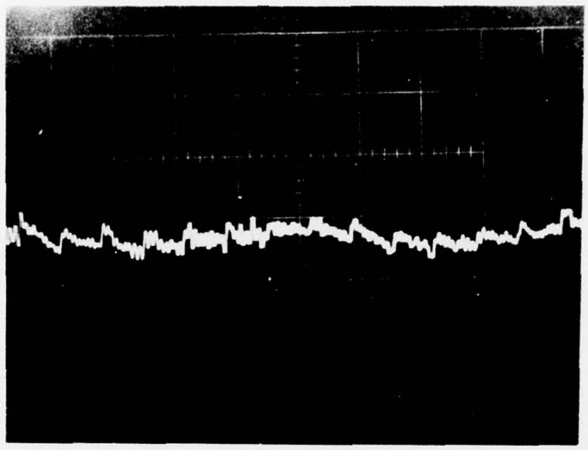
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
16.7KV set
2.65 Amps

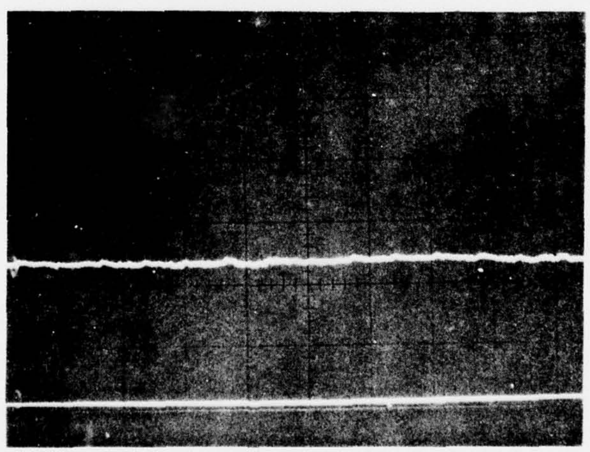
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 12 DISCHARGE RIPPLE WITH BOTH SIDES OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
16.7KV set
1.325 Amps

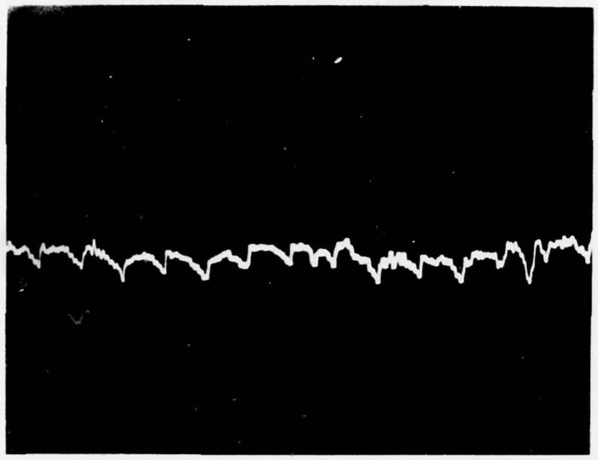
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
16.7KV set
1.3 Amps

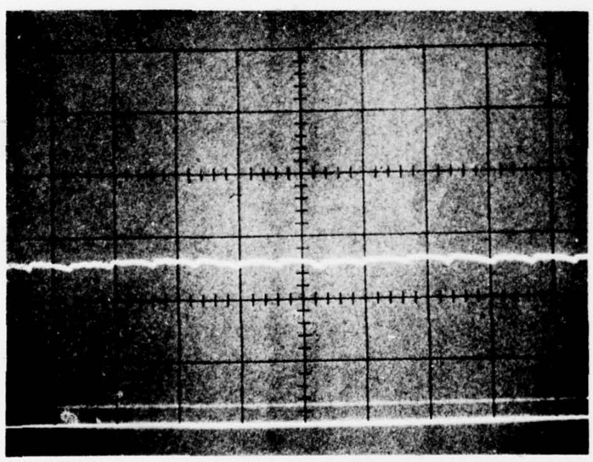
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 13 DISCHARGE RIPPLE WITH ONE SIDE OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
14.7KV set
1.5 Amps

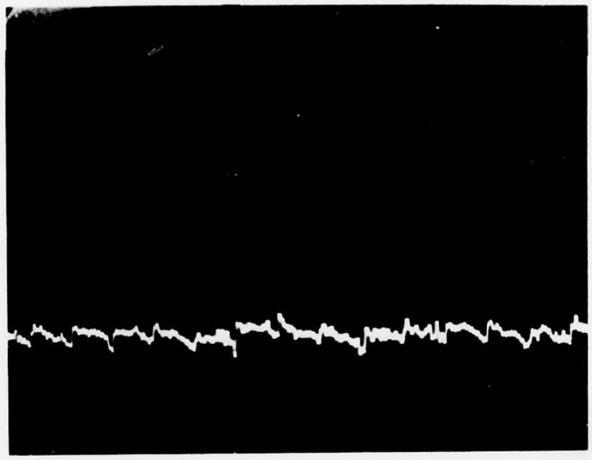
EXPANDED STEADY STATE VOLTAGE



Vertical 5KV/div
Horizontal 2msec/div
14.7KV set
1.5 Amps

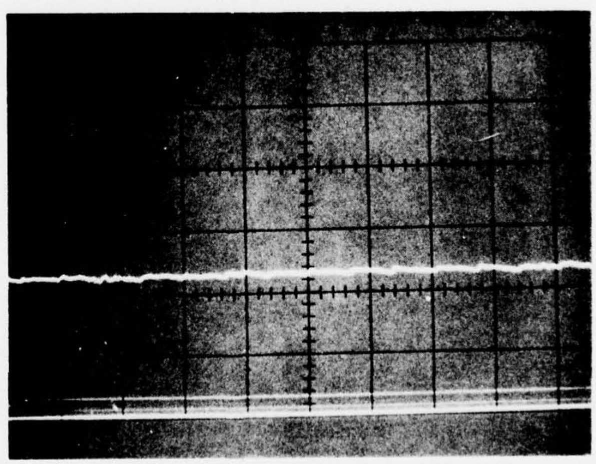
TOTAL STEADY STATE VOLTAGE WITH BASELINE

FIGURE 14 POWER SUPPLY RIPPLE WITH ONE SIDE OF LASER DISCHARGING



Vertical 1KV/div
Horizontal 2msec/div
14.7KV set
1.5 Amps

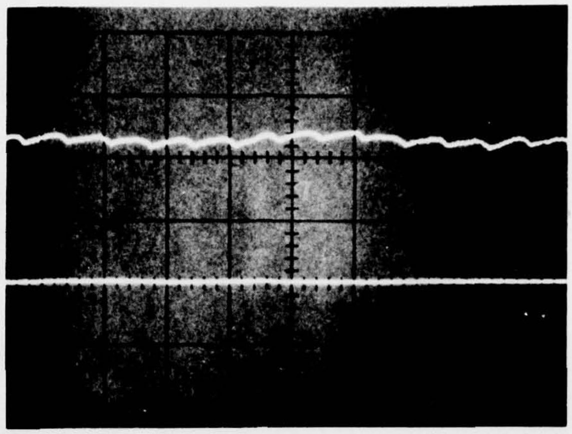
EXPANDED STEADY STATE VOLTAGE



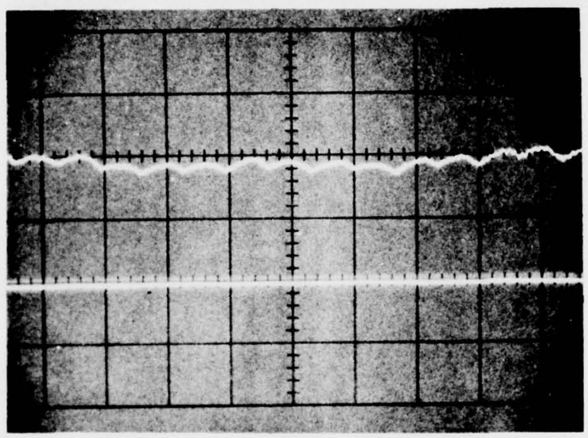
Vertical 5KV/div
Horizontal 2msec/div
14.7KV set
1.5 Amps

TOTAL STEADY STATE VOLTAGE WITH BASELINE

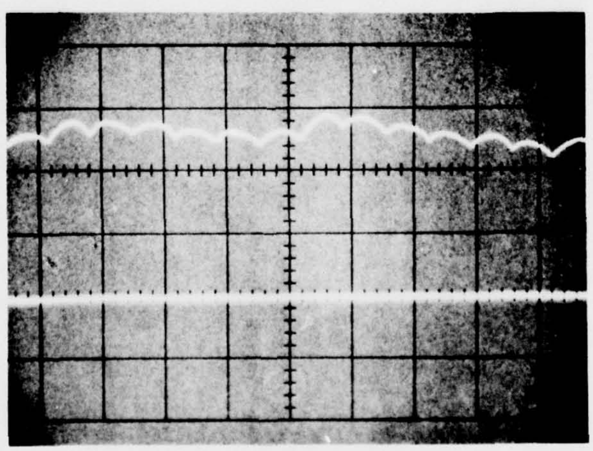
FIGURE 15 DISCHARGE RIPPLE WITHOUT CURRENT REGULATOR WITH ONE SIDE OF LASER DISCHARGING



BOTH SIDES DISCHARGING
CURRENT REG. IN
Vertical .59 Amps/div
Horizontal 2msec/div
16.7KV set



ONE SIDE DISCHARGING
CURRENT REG. IN
Vertical .59 Amps/div
Horizontal 2msec/div
14.7KV set



ONE SIDE DISCHARGING
CURRENT REG. OUT
Vertical .59 Amps/div
Horizontal 2msec/div
14.7KV set

FIGURE 16 CURRENT RIPPLE AT INDICATED CONDITIONS

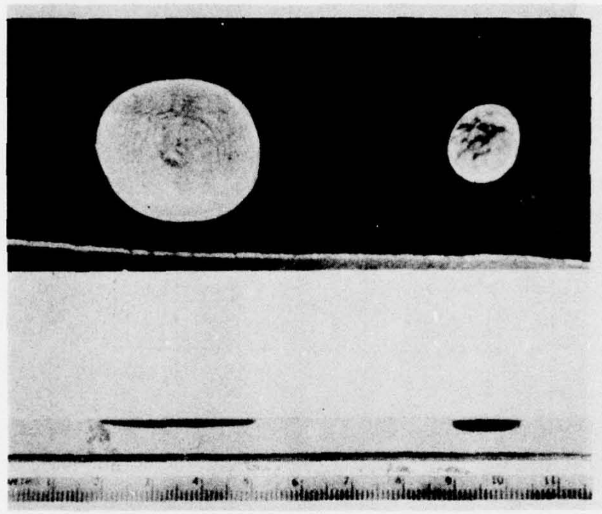


FIGURE 17 BEAM QUALITY OF LASER SYSTEM

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